N62-10006
550730 p24

NASA TN D-1144

NASA TN D-1144

TECHNICAL NOTE

D-1144

AN ACCELERATED RESERVOIR LIGHT-GAS GUN

By John S. Curtis

Ames Research Center
Moffett Field, Calif.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON February 1962

1J

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-1144

AN ACCELERATED RESERVOIR LIGHT-GAS GUN

By John S. Curtis

SUMMARY

Simple modifications in design and operation of the 0.22-caliber piston-compression light-gas gun, described in NACA TN 4143, have resulted in an increase in muzzle velocity from 15,000 to 29,700 feet per second. A contracting tapered section was added at the high-pressure end of the pump tube. The forward 4 inches of the pump piston, made of high-density polyethylene plastic, is forced to intrude into the tapered coupling and launch tube during the launching sequence. Hydrogen has been substituted for helium as the working gas. The effect on performance of varying several important parameters is demonstrated.

INTRODUCTION

The development of a new class of high-performance gun was started with the invention of the light-gas gun by Dr. W. D. Crozier at the New Mexico School of Mines in 1946. The reasoning that led to this invention involved the observation that the performance of propellant gases improves as temperature increases and molecular weight decreases. In addition to these two effects, it is axiomatic that increases in working pressure and reductions in projectile mass will permit attainment of higher muzzle velocity.

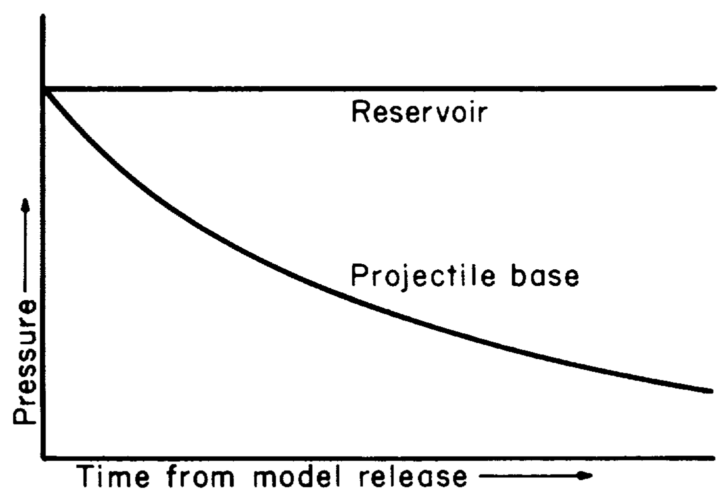
All light-gas guns have been designed to provide a reservoir of hot, low-molecular-weight gas at the highest manageable pressure. The earliest light-gas guns were operated with helium, but hydrogen has proven recently to be markedly superior. Two different compression processes have been used to heat the propellant gases in guns at the Ames Research Center; one is essentially isentropic compression of a large volume of hydrogen using a heavy piston in a long, large tube called the pump tube (ref. 1), and the other is a multiple-shock compression of a somewhat smaller volume of gas (ref. 2). In the case of isentropic compression it is vital that the model be restrained from starting its traverse of the launch tube until the propellant-gas pressure reaches a high level. One means of achieving this restraint lies in the use of a break valve designed by Mr. Layton Yee of the Ames Research Center. In both types of gun the pump tubes are coupled to small-caliber gun barrels with heavy steel couplings; both types of gun are currently capable of firing useful models at speeds below 25,000 ft/sec.

The present investigation was undertaken to improve the performance of the isentropic-compression gun, because it appeared to offer better prospects for significant increases both in muzzle velocity and in the capability of launching relatively delicate models.

GUN DESIGN CONSIDERATIONS

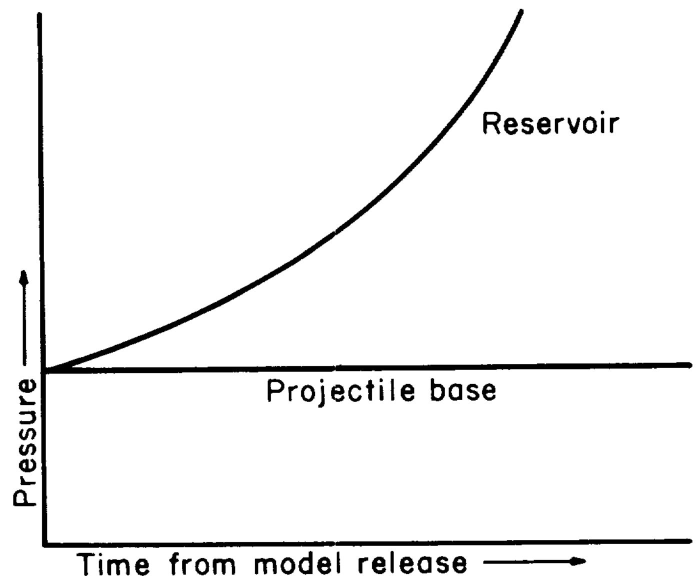
There are two pressure limits which cannot be exceeded in successful repeated operation of any gun. First, the ultimate pressure level of the gun itself must not be exceeded, and second, the pressure applied to the projectile base is limited by the strength of the projectile. In practice, it is found that the limiting pressure of the gun is usually higher than the pressure that can be withstood by the model.

Consider then a gun which has a constant reservoir pressure limited to the maximum allowable model base pressure. (See sketch (a).) Note

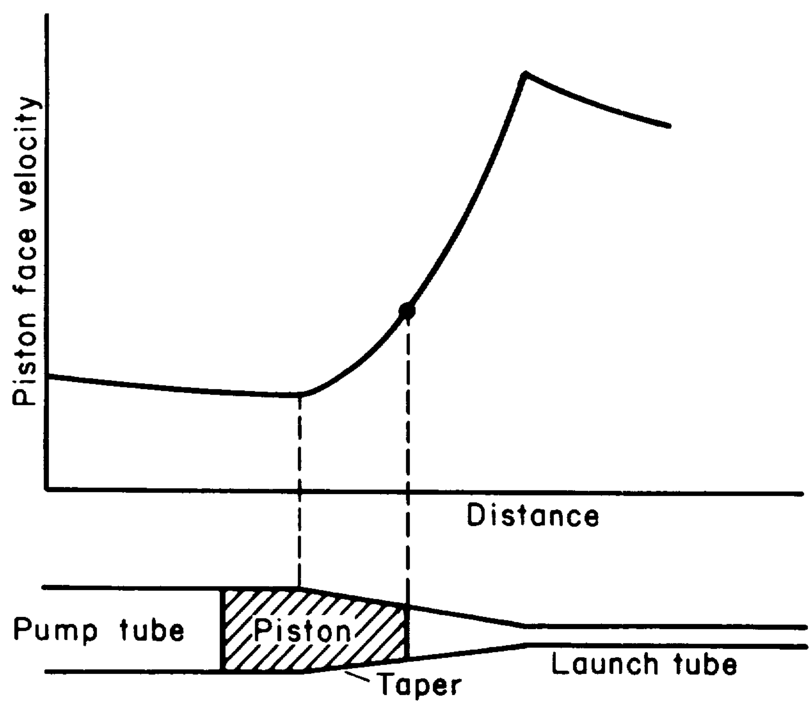


Sketch (a)

that the base pressure drops rapidly as the projectile accelerates. The base pressure can be kept from falling only by adding energy to the gas system after model release. The pump piston can provide this energy by continuing to compress the reservoir gas after the projectile is released. To maintain constant base pressure by this means the reservoir pressure must rise in a prescribed manner as illustrated in sketch (b). Unfortunately, as the launch times are extended to obtain increasingly higher velocities, a limitation of this method is reached when the reservoir pressure rises to the maximum allowable pressure of the gun. However, by the addition of energy to the propelling gas in a form other than pressure energy, an increase in gun performance can be obtained beyond this limitation. For example, kinetic energy would be added to the gas if the entire reservoir could be accelerated to high speed. This accelerated reservoir would then serve to lessen the pressure difference between the piston and the base of the model. A means proposed to accomplish this consists of addition of a tapered section to the high-pressure end of the pump tube. The conventional piston is replaced with a deformable and relatively incompressible piston. It is reasoned that during the compression cycle as the piston is forced through the tapered section, the forward piston face will accelerate to high speeds because of the contraction. The velocity of the front face of the piston might vary in the manner shown in sketch (c). If the piston continues on into the



Sketch (b)



Sketch (c)

launch tube during the latter part of the launching cycle, a further gain in performance would be realized from this moving reservoir. The expansion of the gas from piston face to model base would be less (and the resulting base pressure higher) than would be the case if the piston stopped at the end of the pump.

Modifications were made to an existing piston-compression light-gas gun to investigate the design considerations discussed above.

DESCRIPTION OF GUN AND FIRING CYCLE

A 505

The gun used in the first part of this investigation (fig. 1) is exactly the gun of reference 1 with two principal modifications. A complete description of this gun before modification is given in reference 1. The original high-pressure coupling was replaced with one having a gentle internal taper and a pump-tube extension (fig. 2). The taper offsets are given in table I. A pump piston of different design was devised and is shown in figure 3 both before and after use. The pump piston is shown in an exploded view in figure 4. The front part is composed of high-density polyethylene, typically 4 inches long, and has a diameter which allows a free-sliding fit in the pump tube. The base of the piston is constructed of steel and threads into the front. A seal ring and shear disk are held in place on the base of the piston by a nut. The shear disk is cut from 0.015-inch-thick brass shim stock and is used to prevent any motion of the pump piston until the powder pressure is high enough to insure repeatable burning rates.

The gun consists essentially of a pump tube, launch tube, high-pressure coupling, and a powder chamber as illustrated in figure 5. Principal dimensions of the equipment are given in table II. At the breech end of the pump tube and at right angles to it is the powder chamber, which is vented to the atmosphere by the 1/16-inch hole drilled through the blowout disk. The blowout disk is constructed of brass and is 1/4 inch thick.

The pump tube extension (provided for the sole purpose of preventing damage to the pump tube in the event unexpectedly high pressures occur) and the tapered coupling are constructed of AISI 4340 steel hardened to Rockwell C-35. The pump-tube extension and the tapered coupling are clamped between the pump-tube flange and the launch-tube flange with steel bolts, as shown in figure 2.

Model Release Methods

Since the operation of all isentropic-compression guns requires that the projectile be restrained until the reservoir pressure rises to a high level, two types of model-release devices have been used in the firings reported here. The first type, a shear disk, is illustrated in figure 6 which shows the disk before and after use and also the manner in which it is installed in the gun. The shear disk is designed to release the model when the gas in the coupling reaches a pressure of 20,000 lb/sq in.

The second type of release device used is the break valve mentioned in the Introduction. Figure 7 shows the break valve and valve holder prior to installation in the gun. Slots cut in the downstream face and sides of the valve control the location of the break. A deep, wedge-shaped slot is provided in the upstream face of the valve and the gas in the high-pressure coupling is allowed access to this slot to provide the force necessary to break the valve and move the two halves aside. The installed position of the break valve is also shown in figure 7. The valves are cast from 142-T571 aluminum.

Sequence of Events During Firing

In preparation for firing, the pump tube, launch tube, and test chamber were evacuated. The pump tube was then charged with hydrogen to the selected pressure, and the powder charge inserted in the powder chamber. The powder was ignited and when the pressure rose near [illegible],000 lb/sq in., the shear disk on the pump piston sheared and the piston started to move. During a major portion of the piston travel, the pressure of the powder gas is much higher than the pressure of the hydrogen. Only toward the end of the pumping sequence does the hydrogen pressure become greater than the powder pressure. A typical loading condition is such that when the front face of the piston is near the entrance to the tapered coupling the hydrogen pressure in the coupling reaches 20,000 psi, sufficient to release the model and begin the launch.

The piston continues to move forward and the front of the piston is forced into the tapered coupling. In the present tests a portion of plastic frequently detached from the front face of the piston and followed the model through the launch tube. All the hydrogen in the pump tube then became trapped between the detached portion of the piston and the model.

TESTS AND PERFORMANCE

Four important parameters were varied in the test program: tapered-coupling contour, compression ratio, initial gas pressure, and gun-powder weight. Compression ratio is defined here as the ratio of gas volume before firing to gas volume when compressed to 20,000 psi. During each set of tests all conditions were held constant except the powder charge, which was increased cautiously until damage to the gun was observed or appeared imminent. Pertinent details of all tests are given in table III.

The effect of varying initial pressure of hydrogen (with short pump tube and Coupling A) is shown in figure 8. It is shown that reducing initial hydrogen pressure for a given powder charge yields higher velocity up to the point at which the gun is damaged. It should be emphasized that changing hydrogen charging pressure changes the compression ratio in these series. The rate at which the reservoir pressure varies after model release is also strongly affected. The jagged line drawn across each curve near its upper end indicates the point at which damage was noted. To prevent damage and increase velocity it is necessary to add both gun powder and hydrogen.

The performance of the gun with three different taper designs is shown in figure 9. The tapers effectively differed in length as well as in contour. The differences noted demonstrate clearly that this is a most important and incompletely understood design feature. Distorted couplings have been used in a number of rounds. These rounds, some of which gave excellent performance, are included in table III.

The effect of compression ratio on performance in the present test series is shown in figure 10. The tapered coupling used for the tests at the higher compression ratio had been slightly deformed previously. Since coupling design has a strong influence on performance, the changes due to compression-ratio increase may have been masked by the distortion. It is expected that a really large increase in compression ratio would be an important design improvement.

VELOCITY MEASUREMENT

The projectile velocities were derived from time-distance records of the flight past calibrated spark-shadowgraph stations. The combined errors in distance and time measurements led to an estimated maximum error of ±1 percent in velocity. Two shadowgraphs from the range are shown in figure 11. The contrast between the low- and high-speed examples clearly illustrates the distance traveled by the model during the 0.2-microsecond duration of the spark-light source.

A rough check on the measurement of velocity was provided by the craters struck in aluminum plates by the test models. Figure 12 shows the variation of crater depth with model velocity. This curve was used to eliminate the possibility of gross error in velocity measurement arising from failure of the electronic interval counter used for measuring time. Round 30 is the only test that showed a large discrepancy in crater depth.

CONCLUDING REMARKS

The modification in design and operation of a light-gas gun have permitted attainment of muzzle velocities up to 30,000 feet per second for 0.22-caliber models. The critical design feature of the gun is the gently tapered coupling, between the pump and launch tubes, through which the pump piston is forced rapidly into the launch tube, thereby making it possible to accelerate the entire reservoir of hydrogen propellant to high speed. This feature also relaxes the restriction on usable compression ratio common to other light-gas guns because no gas buffer is necessary to prevent damage to the gun. Therefore higher gas temperatures may be attained. Some further increases in compression ratio, and hence in peak temperature, should be permissible without making erosion too serious a problem, because the launch-tube erosion in the present tests was less than 0.001-inch increase in bore diameter per shot even for the high-speed rounds.

A 5 0 5

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Sept. 6, 1961

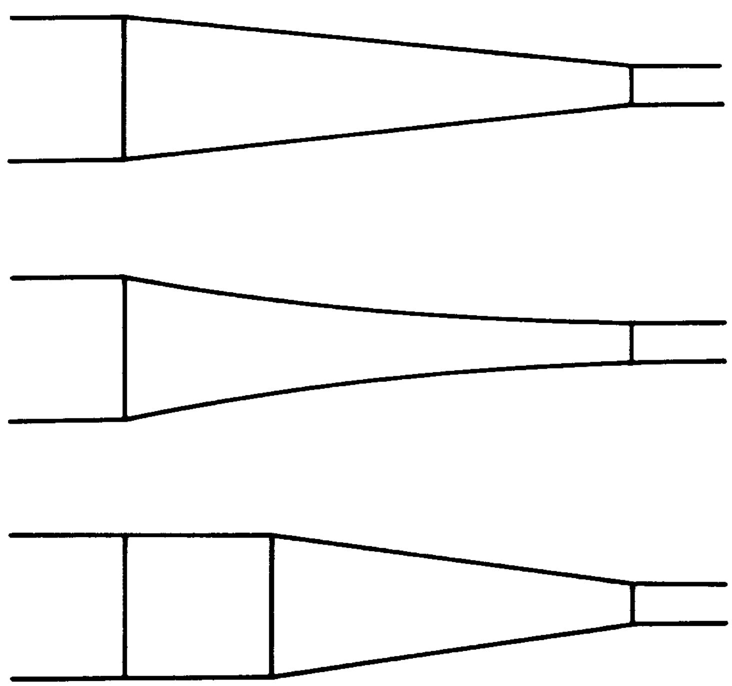
REFERENCES

1. Charters, A. C., Denardo, B. Pat, and Rossow, Vernon J.: Development of a Piston-Compressor Type Light-Gas Gun for the Launching of Free-Flight Models at High Velocity. NACA TN 4143, 1957.

2. Bioletti, Carlton, and Cunningham, Bernard E.: A High-Velocity Gun Employing a Shock-Compressed Light Gas. NASA TN D-307, 1960.

TABLE I.- OFFSETS FOR TAPERED COUPLING

Station, inches from breech end	Coupling bore diamater, in.		
	A	B	C
0	0.790	0.790	0.790
1/2	.745	.720	.790
1	.699	.636	.790
1-1/2	.654	.566	.727
2	.608	.501	.664
2-1/2	.563	.442	.600
3	.518	.388	.537
3-1/2	.472	.344	.474
4	.427	.305	.411
4-1/2	.381	.271	.348
5	.336	.243	.284
5-1/2	.291	.221	.221
6	.245	.210	.210
6-1/2	.200	.200	.200



Coupling A

Coupling B

Coupling C

A505

TABLE II.- GUN PARAMETERS

Model	
Diameter, in.	0.22
Length, in.	0.15
Weight, grams	0.1
Material	High density polyethylene
Pump piston	
Total weight, grams	90
Base weight, grams	54
Front weight, grams	36
Front material	High density polyethylene
Pump tube	
Diameter, in.	0.79
Length, short, in.	117
Length, long, in.	177
Launch tube	
Diameter, in.	0.22
Length, in.	48
Model release	
Pressure, lb/sq in.	20,000
Test chamber	
Pressure, mm Hg	<10
Powder	
Type	IMR 4227

A
5
0
5

TABLE III.- GUN PERFORMANCE DATA

(a) Short Pump Tube (117 in.)

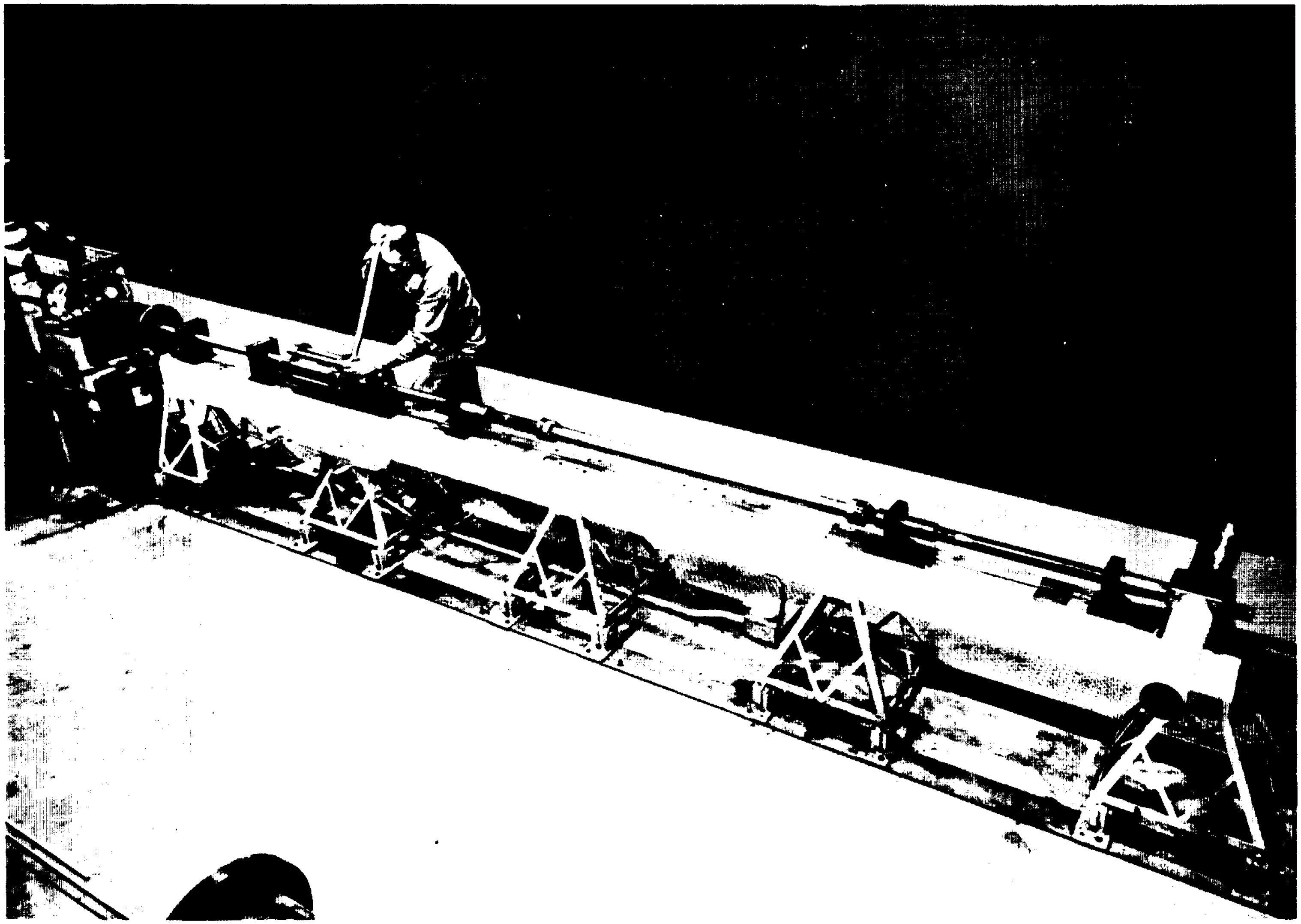
Round number	Powder charge, grams	Charging pressure, psig	Model release (a)	Coupling (b)	Crater depth, in.	Velocity, fps
23	25	50	SD	A	0.217	21,500
25	30	50			.217	21,900
27	45	65			.236	23,500
28	50	67.5			.259	24,500
29	60	67			.277	26,500
30	70	70			.239	26,500
33	50	50			.267	26,000
34	40	100			(c)	22,500
37	50	100			.235	23,400
38	60	100			.242	24,800
39	70	100			.263	26,300
49	30	100		B	.173	19,300
50	50	100			.203	21,200
51	50	50			.242	24,200
55	65	100		C	.270	26,600
56	50	100	BV		.250	24,800
[d]62	70	100			.245	28,100
65	100	130			.249	24,600
68	105	130			.294	28,600

(b) Long Pump Tube (177 in.)

Round number	Powder charge, grams	Charging pressure, psig	Model release (a)	Coupling (b)	Crater depth, in.	Velocity, fps
69	80	78	BV	C	0.288	27,400
70	92	78		C	.294	27,900
71	110	80		A	.305	28,700
80	50	46		C	.276	25,200
82	65	46			.282	26,900
83	100	60			.297	29,100
84	115	60			.310	29,700
85	100	61			.297	28,200
88	65	46			.287	27,000
[e]89	110	60			.283	30,200
91	115	50			.306	29,100

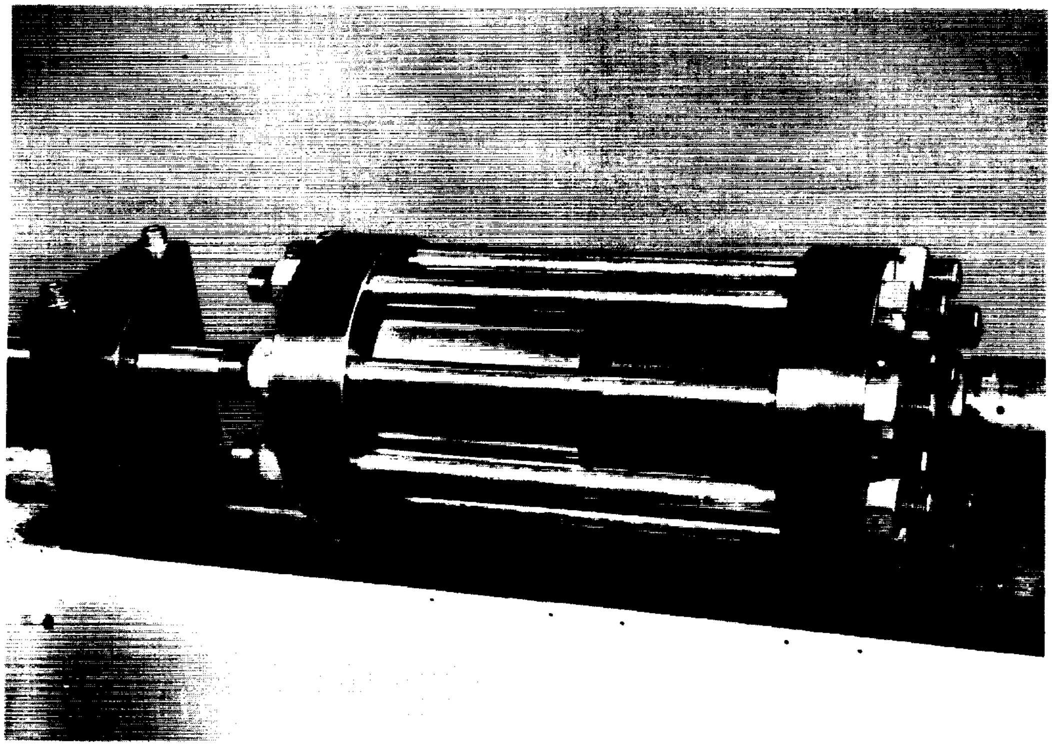
[a]SD - shear disk; BV - break valve.
[b]See table I.
[c]Shear disk hit in the crater made by the model.
[d]Model weight for this shot was 70 mg.
[e]Model weight for this shot was 71 mg.

A505



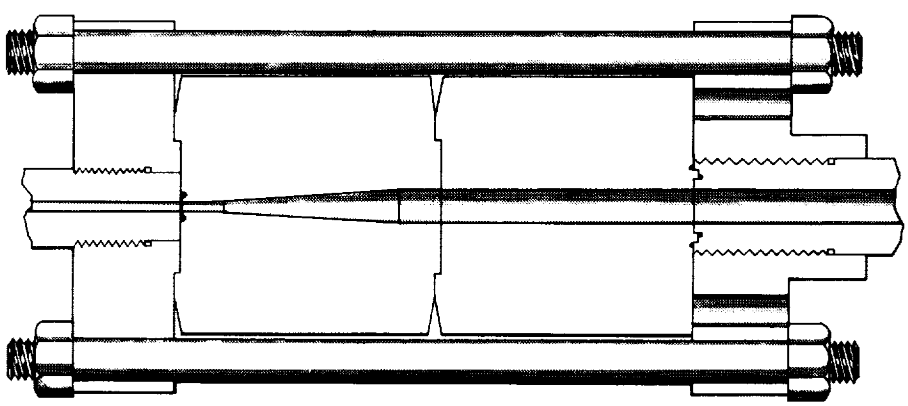
A-27224.1

Figure 1.- Accelerated-reservoir light-gas gun.



Photograph of coupling

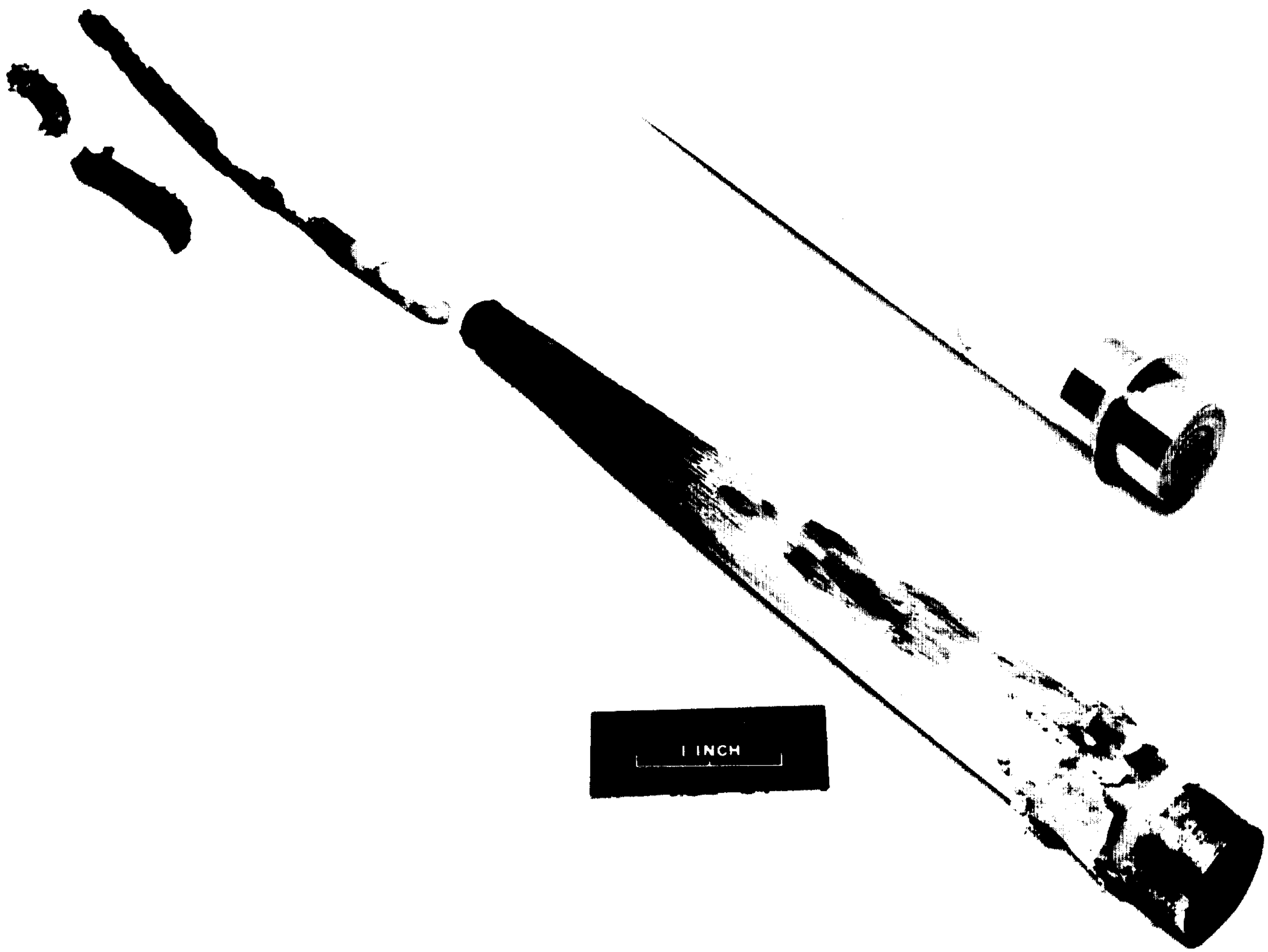
A-27226.1



Cross section of drawing of coupling assembly

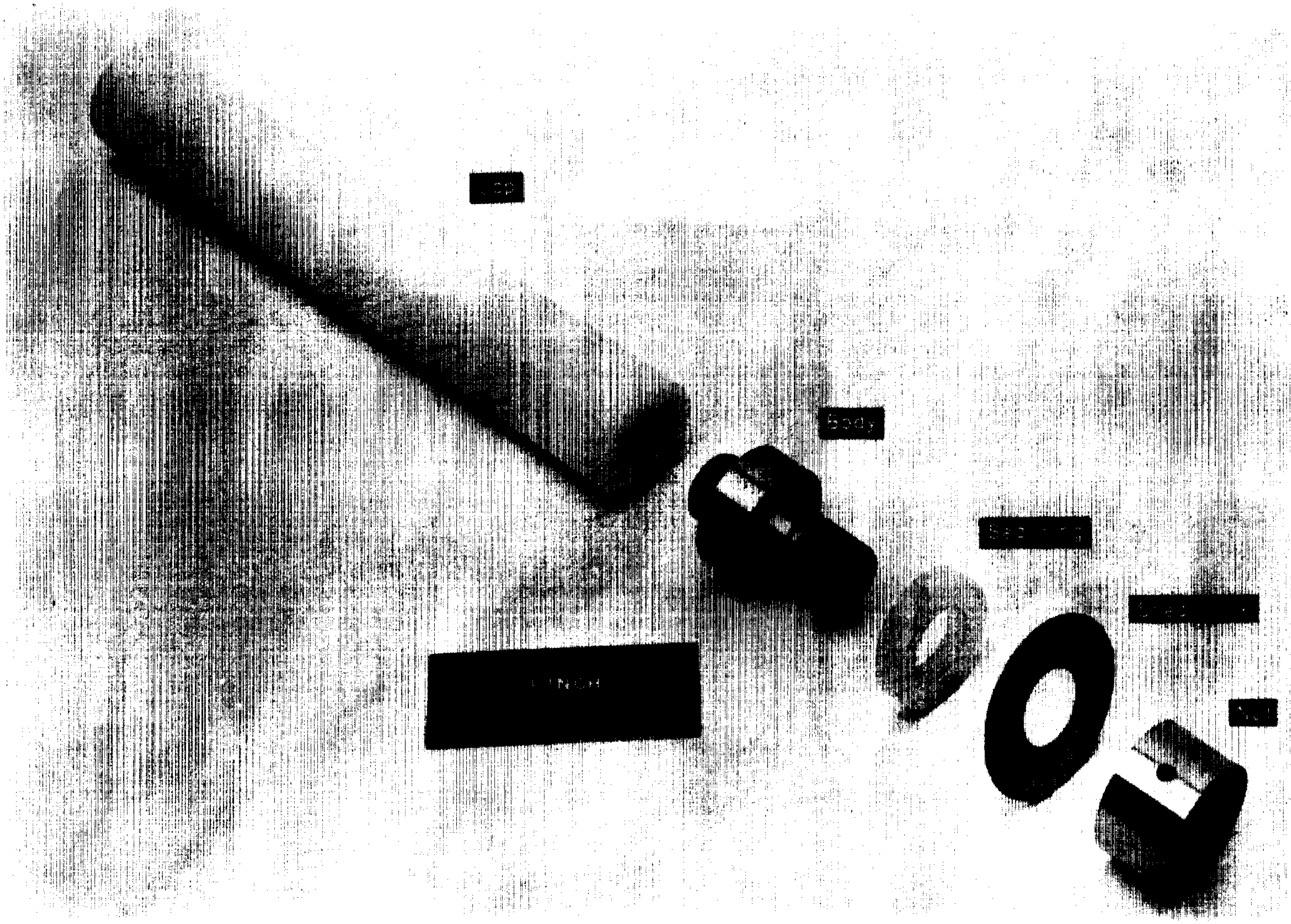
Figure 2.- High-pressure-coupling assembly.

A
5
0
5



A-27227.1

Figure 3- Pump piston before and after firing.



A-27228.1

Figure 4.- Exploded view of pump piston.

A
5
0
5

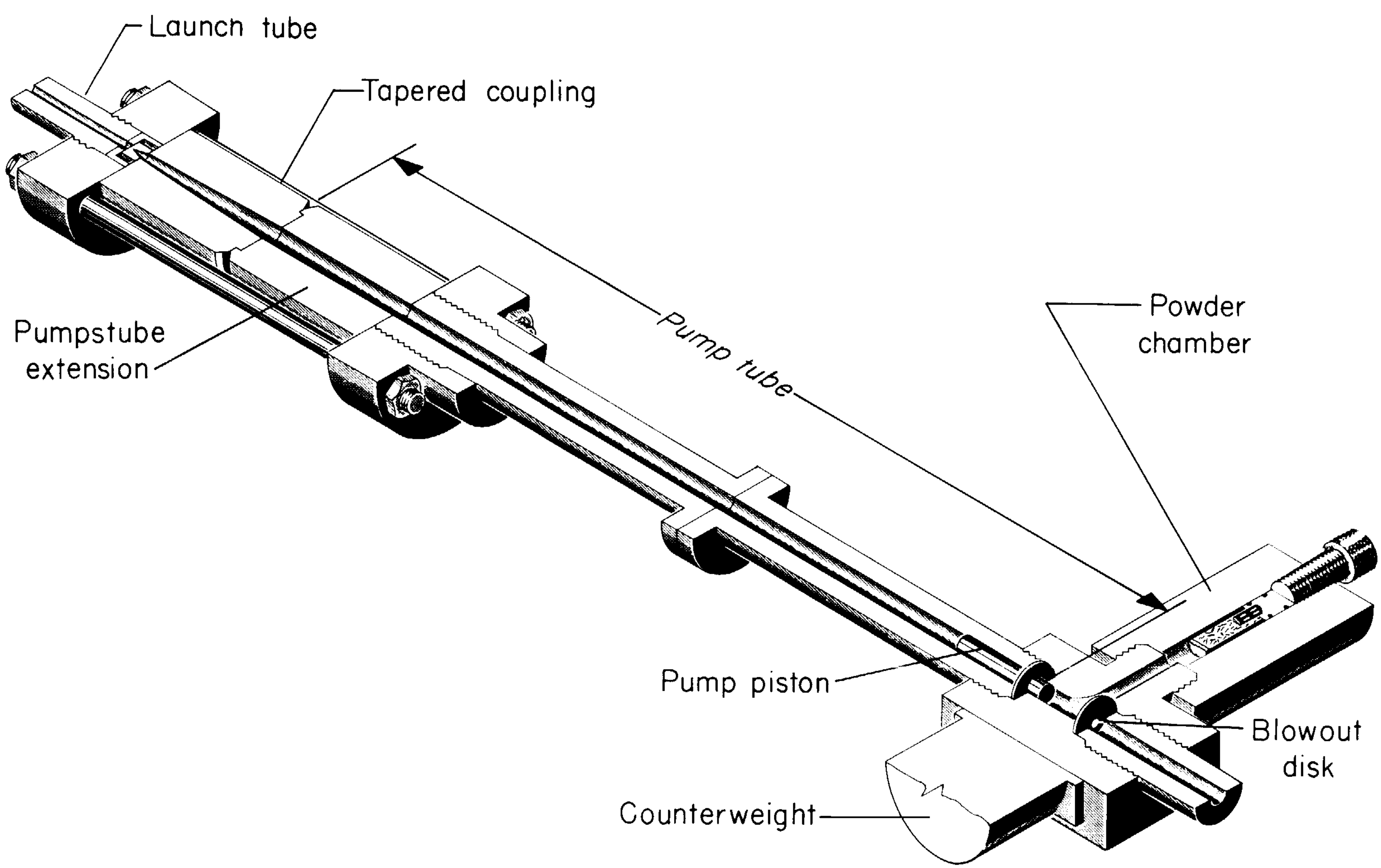
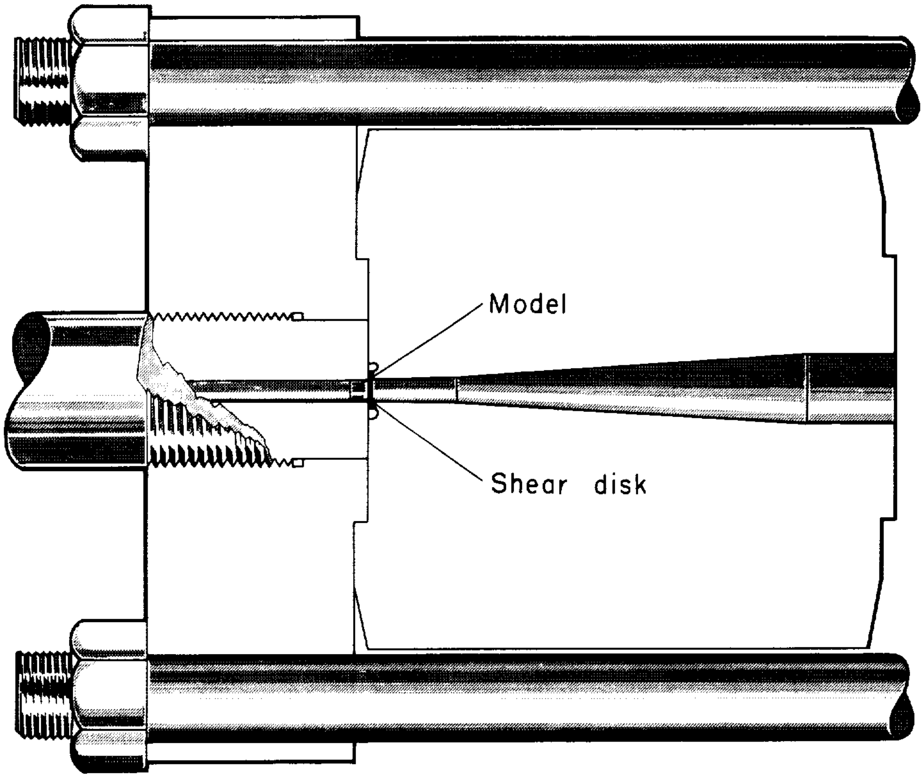
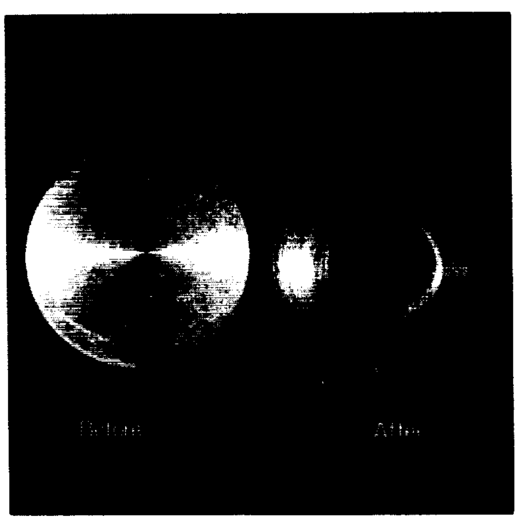


Figure 5.- Cutaway sketch of gun.

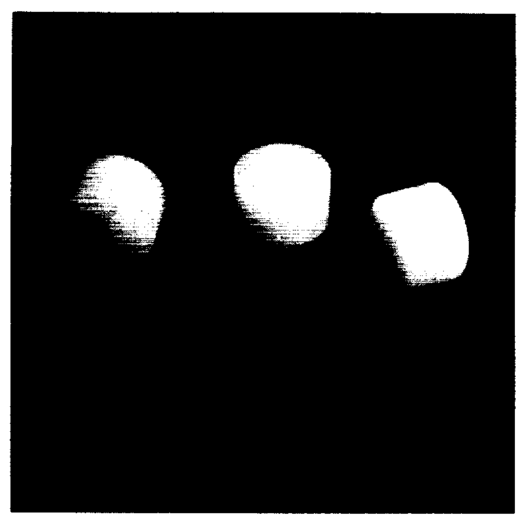


Loading position of shear disk and model



A-27229.1

Shear disk

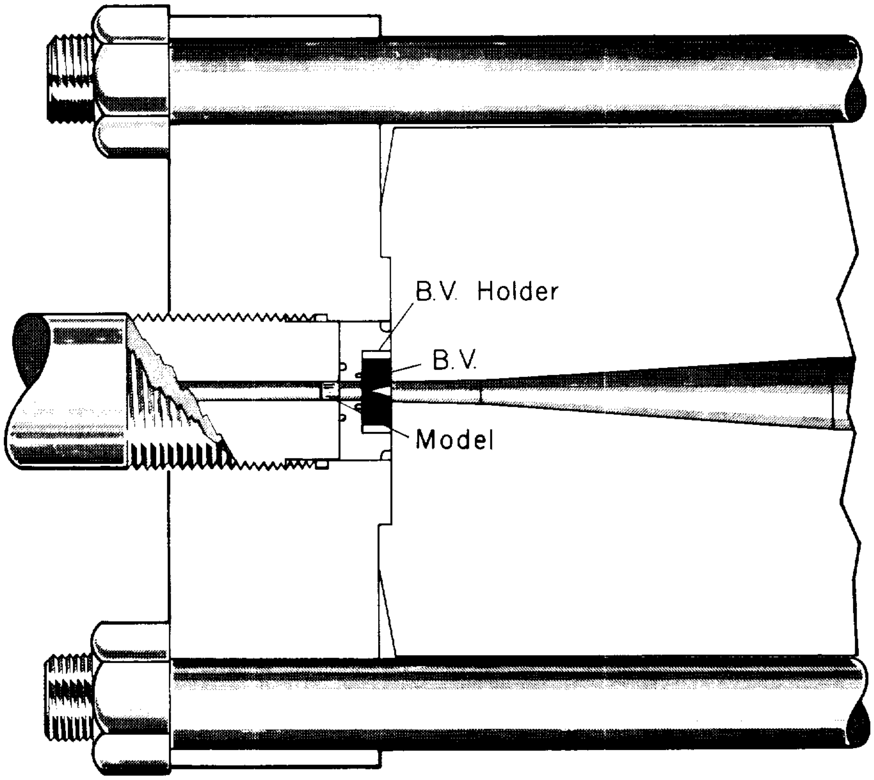


A-27230.1

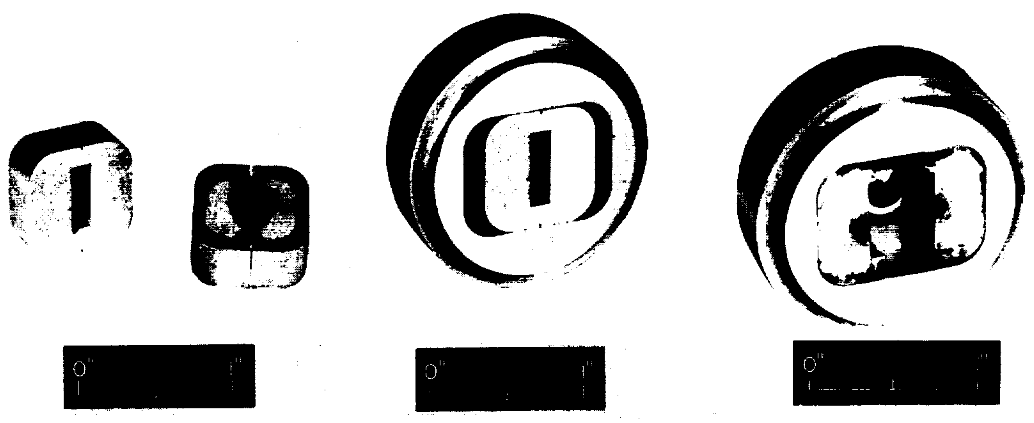
Models

Figure 6.- High-pressure coupling assembly using shear disk.

A
5
0
5



Loading position



Break valves

Break valve assembly

After firing

Figure 7.- High-pressure coupling assembly using break valve.

A
5
0
5

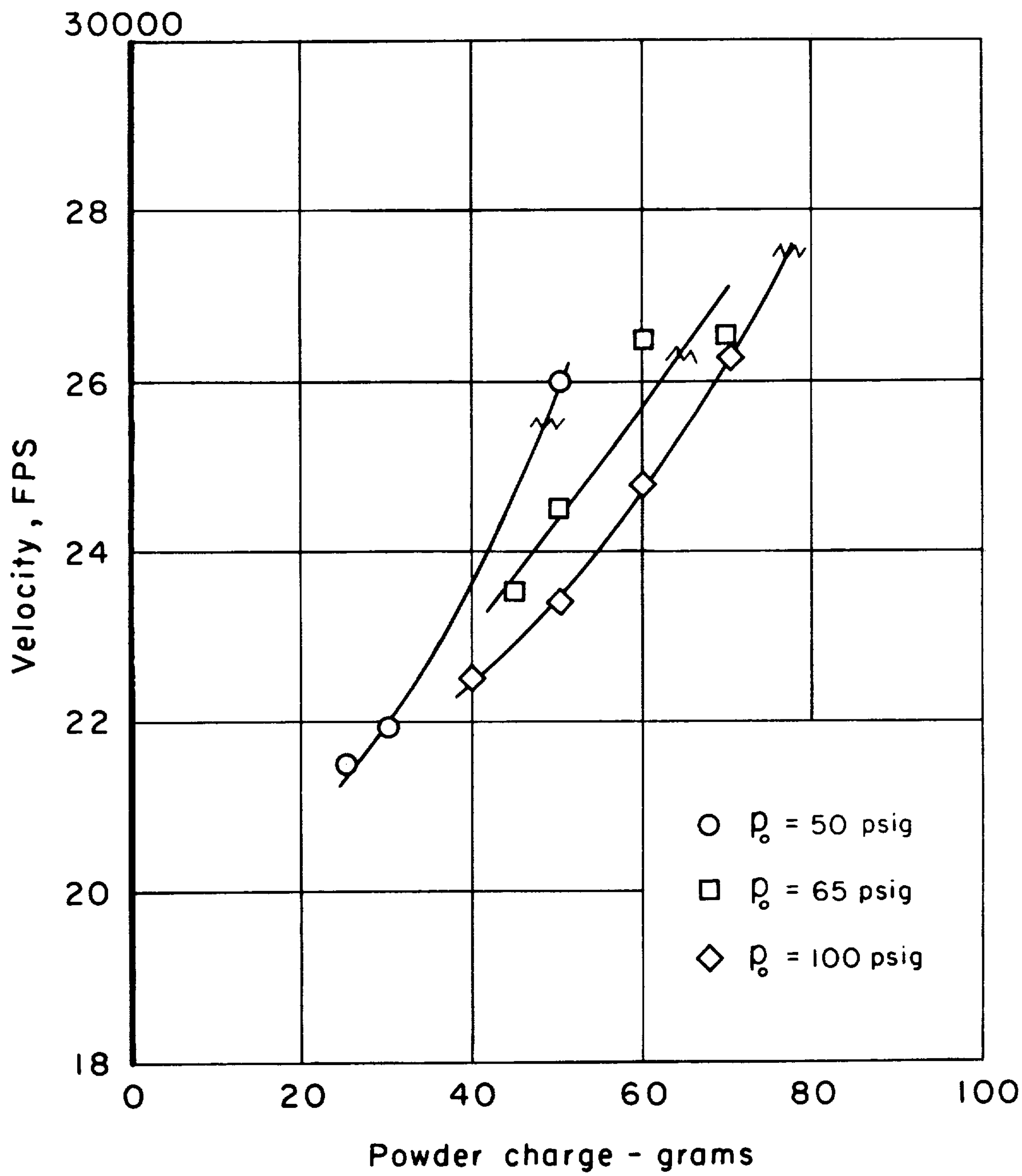


Figure 8.- Muzzle velocities obtained for three hydrogen charging pressures (coupling A and short pump tube).

A
5
0
5

A
5
0
5

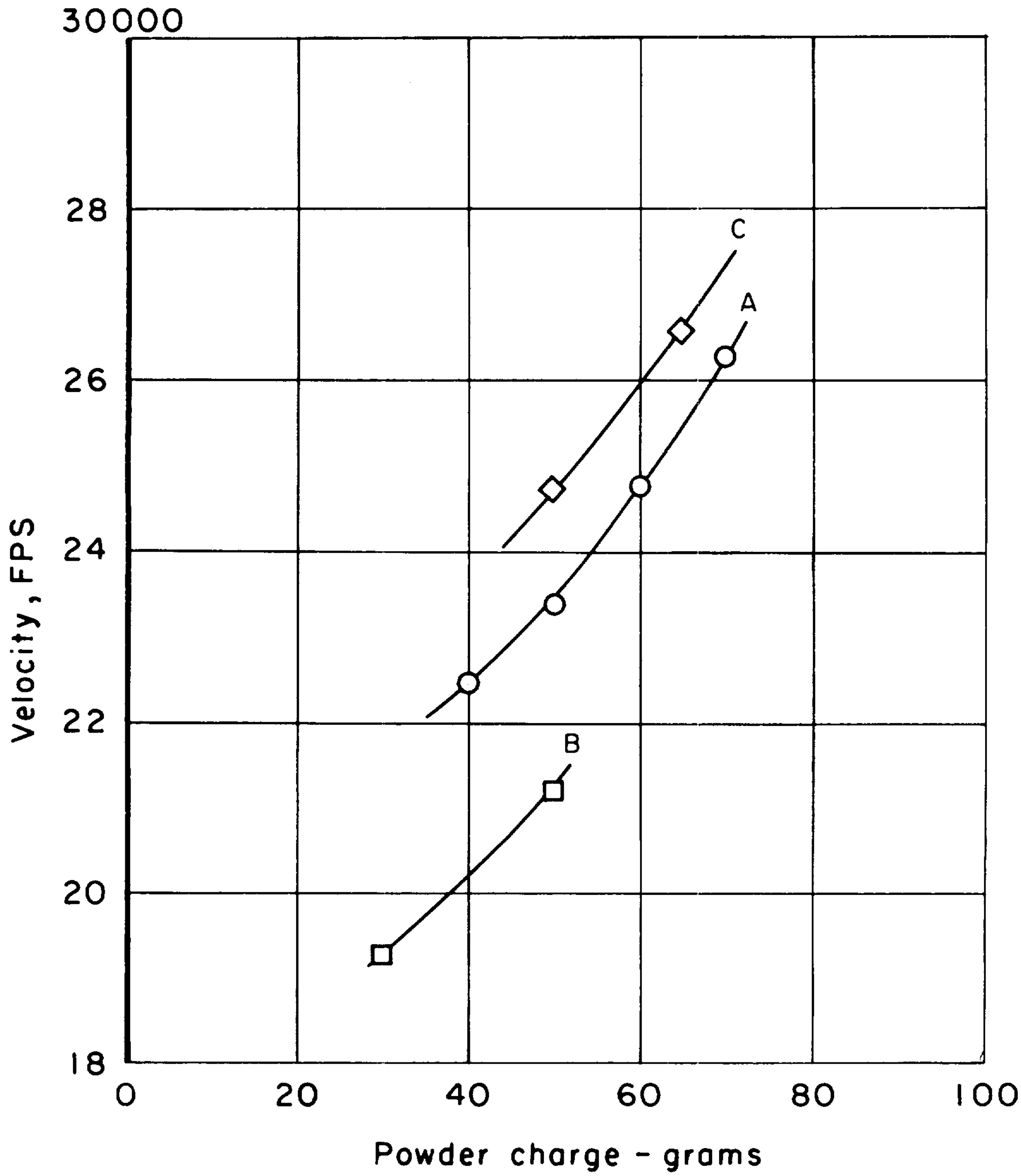


Figure 9.- Muzzle velocities obtained with three different couplings (short pump tube; 100 psig charging pressure).

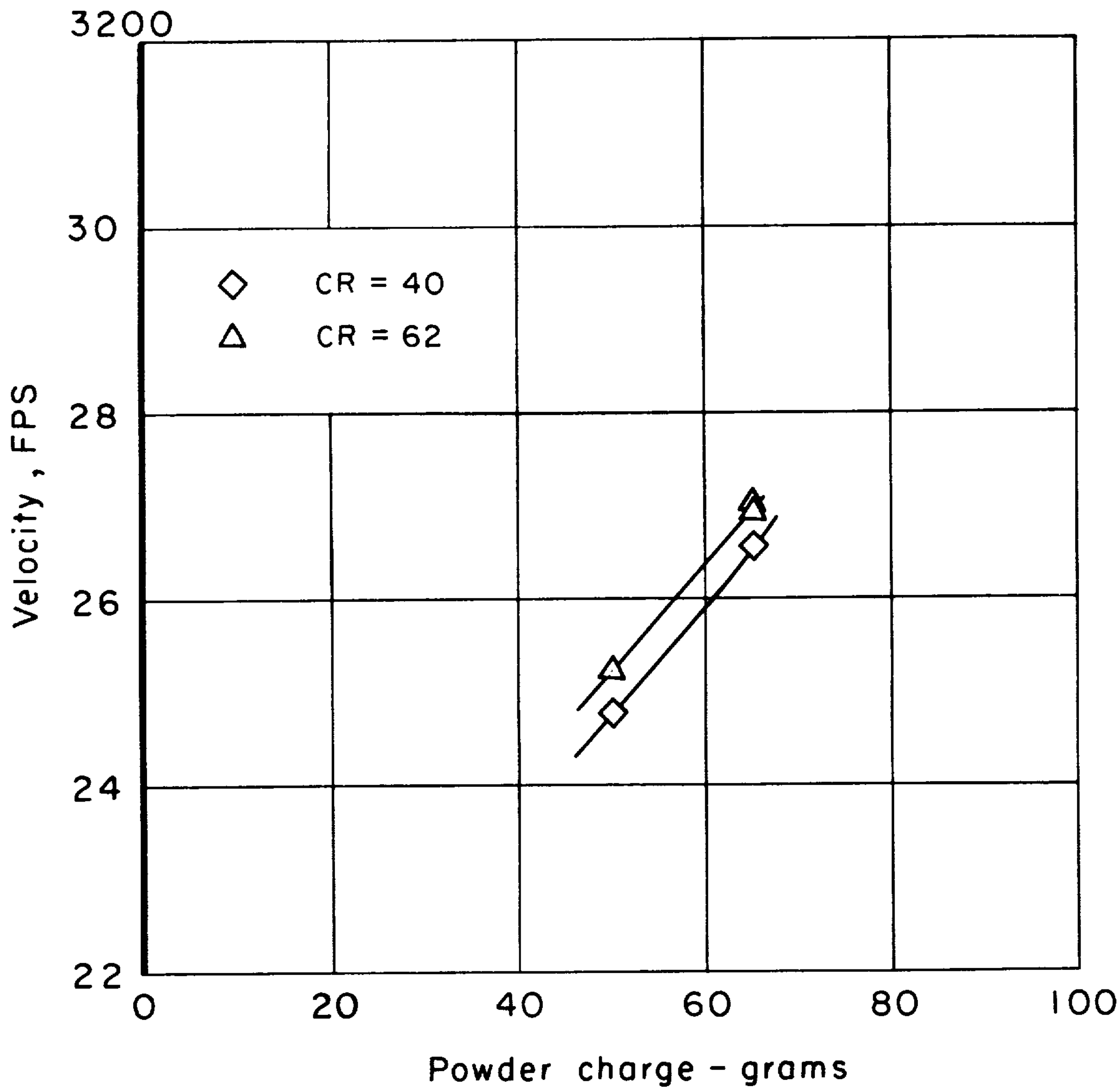
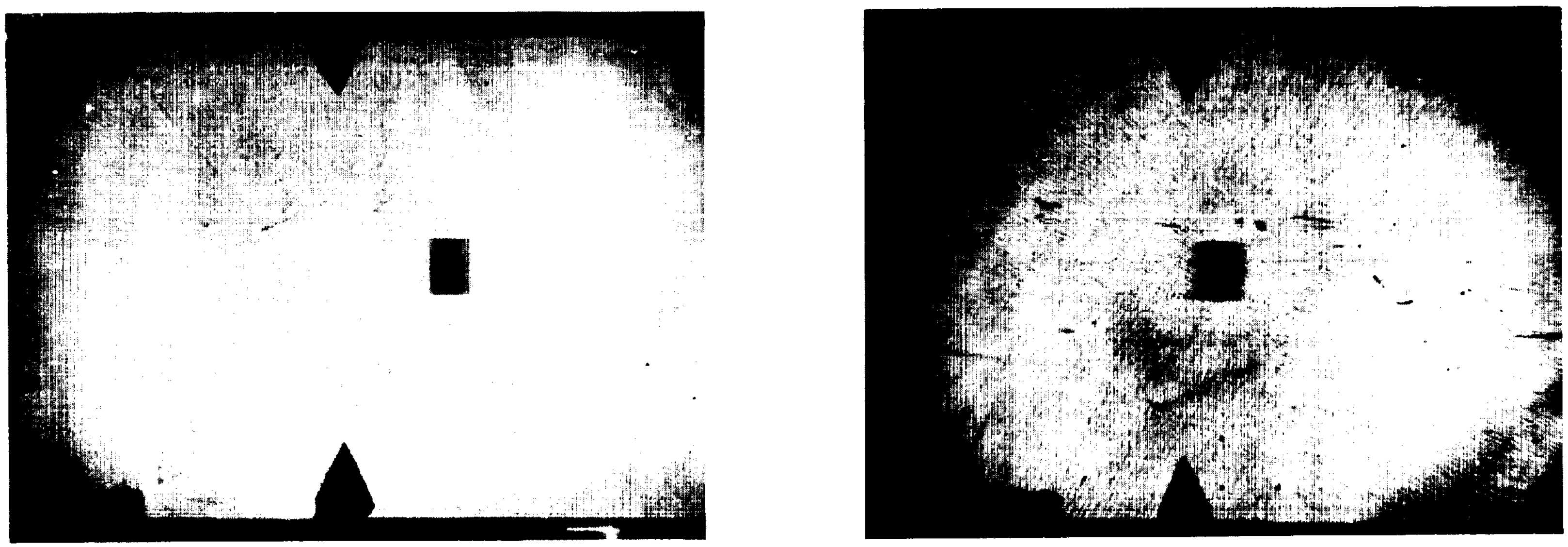


Figure 10- Muzzle velocities obtained for two compression ratios (coupling C).

A505



$V = 6{,}600 \frac{ft}{sec}$ $V = 29{,}700 \frac{ft}{sec}$

Figure 11.- Typical shadowgraphs.

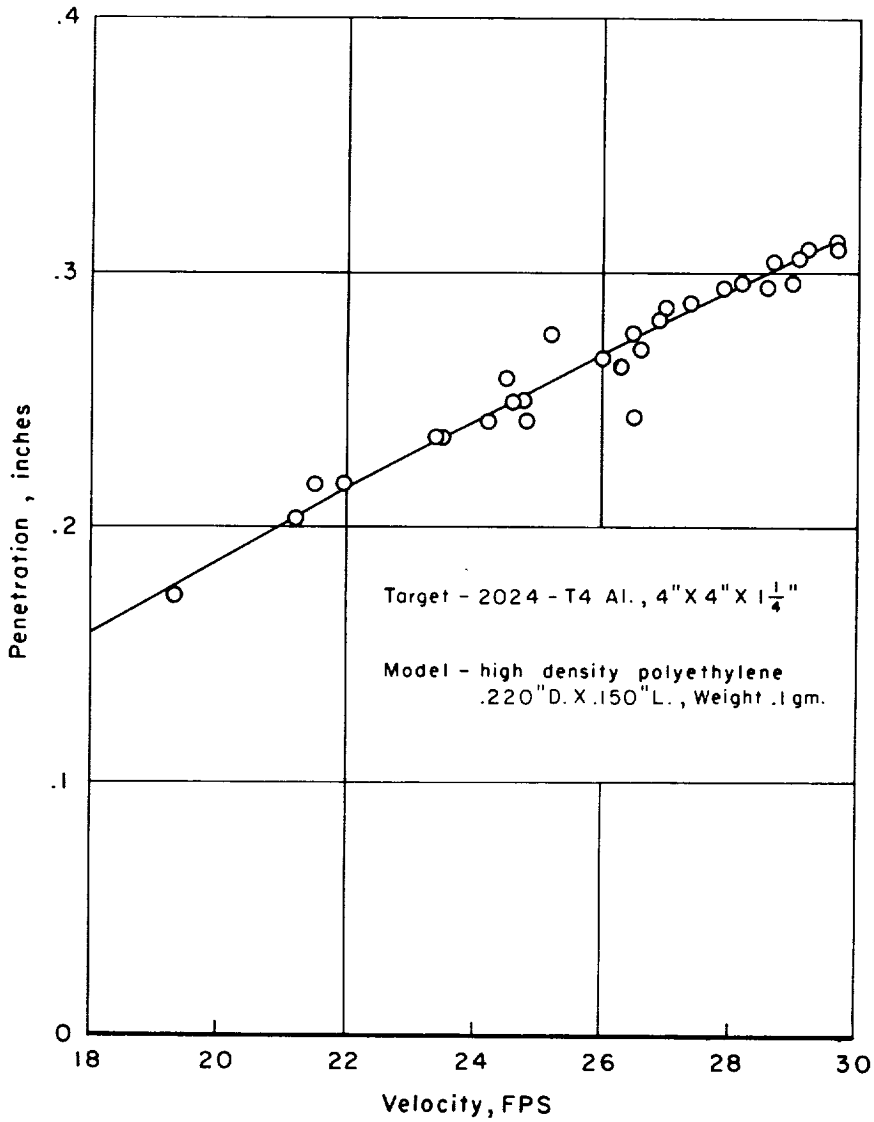


Figure 12.- Target penetration.

A
5
0
5